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Review Article

Looking Back and Ahead on Materials and Technologies of Food Packaging for NASA Space Missions

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ABSTRACT

From carefully documented research by those in the field of science, to day-to-day observations by those of the general public, it's evident: earth's climate is indeed changing, and for the worse. Temperatures across the globe, the sea level, natural disasters as each one of these steadily increase and negatively impact all our lives in various ways, it's equally evident that solutions to handling these changes collectively called “Climate Change” need to be found, which one in particular being taken into consideration is outer space. Thoughts of making outer space a new home for society and venturing to planets miles upon miles away from earth with the intent of inhabiting them too are certainly possible for us humans, given the astounding progress the National Aeronautics and Space Administration (NASA) has made over the years; however, one major hurdle NASA has to overcome in turning those possibilities into reality is their food system. Briefly explaining what a food system is, it's a system comprised of people and their interactions with one other in relation to the food chain, which this is the growing and harvesting of foods, the making safe of them for consumption through processing, then transporting to other processing plants or retailers, selling them, and finally, eating and disposing of them. Returning to NASA's food system, the problem with it is that it will only last for about 18 months in space's environment that's truly unique with its hazards like cosmic rays, solar radiation, and microgravity. Knowing this, NASA, and others through partnerships, has been carrying out a number of studies on their food system, with studies spanning subject matters of how the system's food is grown and processed, to how the system's food is packaged the topic of this paper written as a literature review. At that, this literature review has three objectives: one, to take readers through, and discuss, the major materials and technologies used by NASA in the packaging of foods for space missions, starting with those during the 1960s-1970s; two, to do the same for those during the 1980s-2000s; and three, to do the same, one last time, with materials and technologies being developed and considered for use in future NASA space missions.

Keywords: Climate change; Outer space; NASA; Food system; Food packaging; Materials and technologies

INTRODUCTION

Continuously mounting evidence from research shows that the climate of planet earth is changing, and, unfortunately, not stopping at just the words and numbers of these researches. The changes found, whether subtle or large, have been manifesting themselves year after year through hotter temperatures, a rising sea level, and an increase in the occurrence and strength of extreme weather events. That said, with many understanding the magnitude of the situation, there's been plenty of ideas put forth, and some followed through, in how to handle these changes in the climate, with outer space as one.

Making society a new home out of outer space and planets far-off are a couple interesting thoughts NASA has been exploring, but, as interesting as they are, they're not without their problems.

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The biggest, on the prior note, being their food system. NASA's current food system for space missions lasts about 18 months, where, at that point, astronauts will need a resupply of food, and to do that, during deep space travel, would be very difficult, if not impossible [1]. In addition, there's concern over whether the nutritional value of the food system will be able remain at a level high enough to keep astronauts healthy, due to it being under an extended period of time in outer space's harsh environment of cosmic rays, solar radiation, and little gravity [2]. Thus, it's in knowing that without finding solutions to the aforementioned that living and traveling extensive distances around space won't be possible. So NASA has, along with research partners and those with expressed interest from other industries, done and continues to do numerous researches on their food system covers a range of topics, including how the system's food is cultivated, processed, and packaged, which is the main focus of this study.

Conclusively, this literature review has three objectives: (i) To take readers through, and discuss, the major materials and technologies used by NASA in the packaging of foods for space missions, starting with those during the 1960s-1970s; (ii) To do the same for those during the 1980s-2000s; and (iii) To do the same, one last time, with materials and technologies being developed and considered for use in future NASA space missions.

1960S-1970S MATERIALS AND TECHNOLOGIES

Taking place from 1958-1963, Project Mercury is carried out, the first program to put humans in space by the United States of America [3,4]. Materials used during the time were aluminum, Kraft paper, plexiglass, and plastic, which tubes were made from the aluminum and Kraft paper and accompanied by a polystyrene straw-like extension tube for food consumption, while dispensers came from the plexiglass and clear, three-ply, laminate films from the plastic [4]. As for what foods were packaged in said materials, there were the likes of “semi-solid, sterile tubed foods, fruits, and meat combinations”, “tablets”, and other foods, such as a bite-size dessert in cubic form that the USA Air Force developed for their own aerospace missions [4].

Next, there's the Gemini program of 1965-1966 [3,4]. All foods, this time, were vacuum-sealed in a clear, four-ply, flexible laminate that's inner and outer layers were made of polyethylene with fluorohalocarbon and layers in between them of polyester [4,5]. Adding on, this packaging was rehydrateable, containing a spring-loaded valve an interfacing water dispenser could open for rehydration of freeze-dehydrated foods that were on the menu of this program [4]. Lastly, the opposite end of the package had a feeding tube attached that was constructed from the material polyethylene tubing, and an overwrap was applied to astronauts meals that was made of a polyolefin-aluminum foil-polyester film [4].

On to 1968-1972, the Apollo program begins. With this program, what's seen is a return of packaging from the Gemini program's missions that's either been left the same or modified in some way to improve it [3]. For example, the menu of this program had dehydrated and intermediate moisture foods that were packaged in the same laminate the Gemini program employed, but with a slight modification that gave astronauts the ability to use a spoon with the packaging [4,5].

Thermosatabilized foods now entering the menu, on the other hand, had one of two packaging types: packaging made of a heat-processable laminated material which was a modified version of the polyolefin-aluminum foil-polyester film mentioned in the Gemini program or collapsible aluminum cans and tubes [4]. And finally, there was the usage of a non-flammable fluorohalocarbon film for a meal overwrap [4].

Moving forward one year to 1973, NASA starts the Skylab missions [3,4]. On these missions, aluminum easy open cans in three varying sizes was the packaging used for foods, while beverage packaging was a clear, collapsible, polymeric pouch. The pouch, for added detail, expanded on reconstitution that was achieved by an attachable reconstitution valve [4].

Reaching the end of this section, NASA's last mission in space for the 1970s was the Apollo- Soyuz Test Project in 1975 [6]. On this mission, the spoon-bowl packaging of the Apollo missions was used for dehydrated and intermediate moisture foods [4]. Wet foods' packaging consisted of either the Gemini and Apollo missions' flexible, four-ply, laminate film or the Skylab missions' aluminum easy open can [4]. And for beverages, their packaging was the Skylab missions' modified version of the clear, collapsible, polymeric packaging used for beverages then [4].

1980S-2000S MATERIALS AND TECHNOLOGIES

Jumping six years later to 1981, NASA enters what it calls its “Space Shuttle Era” [3]. In this time that consisted of five mission’s total, the first four labeled by NASA as “Orbital Flight Tests” had an interim food system in place which relied on the Apollo and Skylab missions' packaging materials and technology and those from the Apollo-Soyuz Test Project [7]. For the fifth, and final, mission, that's when the implementation of a new food system happened. Describing the system, both the food and beverage packaging of the Apollo-Soyuz Test Project was replaced by packaging comprised of a Saran-coated, injection-moulded, high-density polyethylene material base and a thermoformed, flexible lid of Saran-coated polyethylene film [5,7]. Not at all the end of what was new with this packaging, it used a now one-piece needle-septum the one of previous systems being nine pieces that allowed the packaging to interface with a new piece of technology aboard NASA's space shuttle: a galley rehydration device that injected a preset volume of hot or cold water into the packaging [5,7]. Notably, it's at that same injection sight on the packaging that the consumption of food was done *via* a straw made of the material polyethylene and connected to tubing, and when this straw was not in use, a clamp made out of plastic was attached to the tubing to close it [7].

Other food packaging materials and technologies of the Space Shuttle Era needing mention include plastic pouches that served as the packaging for natural-form, ready-to-eat foods, pouches of a flexible foil retort material, aluminum cans, bi-metallic cans, packets for condiments that came in a commercial serving-size, polyethylene dropper bottles for salt and pepper in a liquid form, and a single/multi-meal overwrap that was a polyethylene bag [7]. This finishes the materials and technologies of the Space Shuttle Era and next for review are those of the "Space Station Era".

NASA's Space Station Era, officially starting in 2011, has its share of new food packaging materials and technologies [3]. Delving into what these materials and technologies are, there's, first, the packaging for rehydrateable foods and bite-size foods. Both foods have packaging that's a five- layer co-extrusion of nylon, ethylene vinyl alcohol, a tie layer of polyethylene, and linear low-density polyethylene then overwrapped by an aluminum foil laminate [8]. Heading to beverages, packaging for beverages to be aboard the International Space Station remains largely the same as its Space Shuttle Era's version, with the only change being an upgrade in material to one that provides a longer shelf-life: a foil and plastic laminate [9]. And bringing this section of the 1980s-2000s to an end is thermostabilized foods and irradiated foods. These two types of foods' packaging consists of commercial pouches that, along with all previously mentioned foods and their packaging, is placed inside containers [8].

FUTURE MATERIALS AND TECHNOLOGIES

The Coming to the last of the materials and technologies to go through and discuss in this literature review, the gusseted pouch starts off this section as one of the newer packaging technologies to emerge from food research done in the fairly recent year of 2021 [10]. Going into detail, this packaging was created and tested against the thermoformed rehydrateable food packaging NASA currently uses, and what was found was pleasing. Specifically, results showed this new pouch design cost less to produce and weighed less, which these are two highly important factors in planning and doing space missions [10]. Worth noting as well is this packaging has a design that simplifies the three-piece structure of NASA's current thermoformed rehydrateable food packaging to one-piece [10].

Another development from a published study in 2011 on space food packaging showed the effectiveness of an alternative packaging material in consideration for future NASA use: a clear, aluminum oxide-coated plastic laminate [1]. In the study, this material's barrier properties were measured under conditions that astronauts might experience on a spacecraft against those of NASA's primary food packaging material that's a clear, quad-plastic laminate and one other that's a material analogous to the aluminum foil, plastic laminate NASA currently uses as their overwrap for meals [1]. What the major finding here was while the clear quad-plastic laminate failed to provide a sufficient barrier for foods in simulated outer space conditions, the plastic laminates with aluminum materials were able to do so, resulting in the study's researchers believing that with the alternative material showing positive results so far, optimization of the International Space Station's packaging system could someday take place using the material to reduce it to a single package [1].

Shifting focus to interested parties from other industries, quite a lot of innovations in materials and technologies for space food packaging have spawned from them too. The first example is a competition called the Deep Space Food Challenge that was a collaborative effort put together by NASA, Canada's Canadian Space Agency (CSA), and Canada's Privy Council Office (PCO) [11]. A public competition, what its top two winners of 2021 were able to create was technology self-named the "Beehex" and the other "Space Bread" [1]. With Beehex, the one group of winners created technology they described as a "Universal Food Fabricator" which removes water from plants and meats to the point of becoming powdery in form, stores them airtight in cartridge packaging to increase shelf-life, then makes food out of the plants and meats stored in the cartridges when necessary [11]. And as for Space Bread, what the other group of winners created was a food system that makes bread-making in space possible for astronauts by way of a multifunctional plastic bag they can store, combine ingredients in, and bake to create a ready-to-eat, yeast-risen roll [11].

The second example is another competition, but this time NASA in collaboration with a company called InnoCentive that's focus is on open innovation and crowdsourcing [12]. Among this public competition's categories was food, and its winner in the year 2010 submitted an idea for a food packaging material made out of graphite [13]. The material was light, its barrier properties an improvement over NASA's then current packaging, it was compatible with sterilization processes and the disposal requirements of NASA, and it could provide over a three-year shelf-life for foods, however, it fragmented easily, so although it couldn't immediately serve as a food packaging replacement for NASA, it's another that with further study could find itself in use later [14].

The third example is one more collaboration between NASA and a company by the name of Yet to that also deals in open innovation [14]. This collaboration, once again, yielded a competition set up on the premise of individuals from the public and a multitude of educations submitting their ideas pertaining to the challenges presented by space exploration, with "food packaging and protection" as the title of its food category [14]. Summing up its results, it was reported by NASA and Yet to that many of the ideas submitted to the category of "food packaging and protection" complimented those presented in the competition NASA collaborated on with InnoCentive [14].

The fourth, and final, example comes from the author and is only an idea of the author for now, but two recently published studies provide strong evidence for it to be something very much doable. Elaborating, this idea makes use of two materials both of which new to packaging and a powerful technology. The first material is bacterial cellulose, a nanomaterial produced by bacteria that's been showing lots of promise with its physical properties in the packaging industry. The second is *Cladosporium sphaerospermum*, a fungus with the fascinating ability to absorb radiation and convert it into energy for itself like photosynthetic organisms do with sunlight. And, at last, there's three-dimensional (3D) printing, the powerful technology that was mentioned can build practically anything by taking a material, turning it into an ink, and adding it layer by layer on a surface.

Concerning the published studies, what's of significance with them in connection to this idea is that in one, scientists successfully were able to use 3D printing to deposit algae onto bacterial cellulose [15]. What the result of that was a brand new material that had bacterial cellulose's physical properties and the photosynthetic property of algae [15]. In the other study, scientists experienced success again with 3D printing when they used a 3D printer to print three-dimensional structures that were photosynthetic [16]. This was possible by the group of scientists extracting the chloroplasts of spinach and being able to bind them to a "polymer ink," as they called it [16].

Materials, technology, and studies explained, and now the present idea will be explained. Two approaches to it, the first to be discussed here is akin to the first study talked about in the previous paragraph, where with the fungus *Cladosporium sphaerospermum* an extraction of its vesicles would take place to start, and through 3D printing, they would then be deposited on the material bacterial cellulose.

Taking a moment to go into why the vesicles of *Cladosporium sphaerospermum*, it's because the vesicle is believed to be the mechanism by which *Cladosporium sphaerospermum* produces melanin that it absorbs radiation with [17]. On to the second approach, it's similar to the second study talked about in the previous paragraph, where with the fungus *Cladosporium sphaerospermum* a direct extraction of its melanin, rather than melanin-producing structure, would take place to start, and through 3D printing, it would then be bound to a polymer ink that's printable. Taking a moment, this time, to get into the detail of exactly how melanin would be able to bind to an ink, it's been studied and found that melanin actually has the ability to bind many substances [17]. Such the case, either of the two approaches taken in a laboratory setting should theoretically produce a novel material with the impressive physical properties of bacterial cellulose and radio synthetic property of *Cladosporium sphaerospermum* that NASA could use for their food packaging. Of course, implementation of this new material by NASA wouldn't be immediate. Just like all the other materials and technologies spoken about in this section, more study would be need to be done on the material to find and work out any potential deficiencies in it, with an example being its barrier properties maybe needing improvement and that being addressed by laminating it with one or more other packaging materials to supplement those areas lacking. Nevertheless, it's exciting to know that with how far the fields of science, technology, engineering, and mathematics have come that a material likes this could be made and provide foods protection against hazards in space like the aforementioned ones of cosmic rays and solar radiation. In addition, there's also potential for this novel material beyond just foods: there are the astronauts. This material could be used in gear to protect astronauts from the harmful effects of radiation too on future space missions, which this idea was put forth in an article published in 2020 by a group a scientists studying *Cladosporium sphaerospermum* [18]. Thus, it's with that it end this final section of the literature review on material's and technologies, and hope that with these ideas out, they'll find their way into the hands of someone that will use them for the good of humanity.

CONCLUSION

This literature review had three objectives to accomplish. Objective one was to take readers through, and discuss, the major materials and technologies used by NASA in the packaging of foods for space missions, starting with those during the 1960s-1970s. This was accomplished, and done so, first, by going through the materials listed as follows: Aluminium, kraft paper, plexiglass, polyethylene, fluorohalocarbon, polyester, polyolefin-aluminium foil-polyester, and polystyrene. Next, that time period's technologies were gone through as listed: the packaging tube; dispenser, multi-ply film; polystyrene extension feeding tube; rehydrateable package; meal overwrap; easy open can; and spoon-bowl. Objective two was to do the same as the first objective, but with the major materials and technologies used by NASA during the 1980s-2000s. This was accomplished too, and it was done so by, first, going through the materials listed as follows: Saran, nylon, and ethylene vinyl alcohol. Next, that time period's technologies were gone through as listed: the injection-moulded, high-density polyethylene packaging base; thermoformed flexible lid; one-piece needle septum; rehydration device; condiment packet; dropper bottle; and pouch. Finally, objective three was to do like the previous two objectives, one last time, by ending with materials and technologies being developed and considered for use in future NASA space missions. This, also, was accomplished, and done, first, by going through the materials listed as follows: aluminium oxide-coated plastic laminate; graphite; bacterial cellulose; and *Cladosporium sphaerospermum*. Next, technologies under the same category were gone through as listed: the gusseted pouch; a competition-invented universal food fabricator and multifunctional plastic bag; and 3D printing. At that, this concludes this literature review.

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